Analysis of SBS-Induced Performance Penalties and Their Mitigation in 50G TDM-PON Downstream

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Abstract: We study SBS for 50G TDM-PON downstream showing that considerable performance penalties can occur depending on the specific operating conditions of the transmitter. Frequency dithering can mitigate SBS without impact on other performance metrics. © 2024 The Author(s)

1. Introduction

Stimulated Brillouin Scattering (SBS) is a nonlinear effect that needs to be considered for high-speed passive optical networks (PON) if the optical launch power levels reach/exceed ~10 dBm. For example, such power levels will have to be employed in 50 Gbit/s time division multiplexed (TDM) PON according to ITU-T G.9804.3 [1], in which the optical power loss (OPL) class for C+ allows for a maximum average launch power of up to 14 dBm by the optical line terminal (OLT) transmitter. SBS is associated with backreflection of optical power and eye closures [2], which can render bridging the required OPL challenging. Due to its narrow gain bandwidth, SBS is of particular concern for intensity-modulation / direct-detection (IM/DD) systems, for which the optical carrier is not suppressed, and high power is concentrated in a narrow spectral region. Thus, it must be investigated to which extend SBS effects have to be considered for IM/DD-based 50G PON and SBS mitigation techniques need to be explored regarding their effectiveness and their impact on transmitter performance metrics, such as extinction ratio (ER), optical modulation amplitude (OMA) and transmitter and dispersion eye closure (TDEC). The high launch power requirements for 50G PON result from the intention to keep the costs at the subscriber side low, thus, considering still 25G-class avalanche photodiodes (APDs). An interest in even higher launch powers arises from a considered reach increase to up to 40 km. These tightened power demands require novel transmitters, e.g., a semiconductor optical amplifier (SOA) integrated together with the electro-absorption modulated laser (EML) [3].

In this paper, we analyze the effect of SBS on 50G TDM-PON downstream based on a 50G EML-SOA emitting at 1342.6 nm and provided by a PON technology supplier. We show that SBS-induced power losses of up to ~1 dB can occur depending on the transmission distance and the exact operating conditions of the EML-SOA, e.g., the bias voltage or the drive voltage amplitude. Likewise, the TDEC penalty can exceed several dB, thereby making SBS mitigation imperative. We demonstrate that a 5-kHz dithering of the laser current can fully mitigate SBS without any impact on the transmitter performance metrics, thereby preserving the flexibility for equipment manufacturers and operators to sell/use OLT transmitters without detailed individual SBS characterization.

2. Experimental Setup for SBS Analysis

Figure 1(a) visualizes our experimental setup. The 50G OLT transmitter is an integrated EML-SOA provided by Broadcom Inc. that comprises a distributed feedback (DFB) laser, an electro-absorption modulator (EAM), and an SOA. The EML-SOA operates at 1342.6 nm, provides an optical output power of up to 15 dBm (unmodulated), a dynamic ER $\geq$ 8.0 dB, and a bandwidth exceeding 30 GHz – all in line with the consented 50G PON standard. The on-off keying (OOK) drive signal is generated by a 100 GS/s DAC and amplified before being fed to the EAM. In a first experimental setting ①, we control the launch power into a single-mode fiber (SMF) of 5…40 km length with a variable optical attenuator (VOA) and measure the fiber output power as well as the backscattered power at the output of an optical circulator with optical power meters (PM). Another VOA controls the receive power to a 50-GHz pin photodiode (PIN) connected to a sampling scope, that acts a receiver for TDEC measurements as defined in [1]. Note that for the TDEC measurements, the optical power incident to the photodiode was kept constant. We remove the VOA and the circulator for experiments at maximum launch powers as indicated by the dashed shape outline in Fig. 1(a). For BER measurements, we shift the VOA to the fiber output, setting ②, where it emulates the PON splitter loss and is used to sweep the receive power incident to a 25G-class APD. Offline digital signal processing is performed, including clock recovery, feed-forward equalization with 21 taps, decision-feedback equalization with 1 tap, symbol-to-bit mapping, and BER calculation.

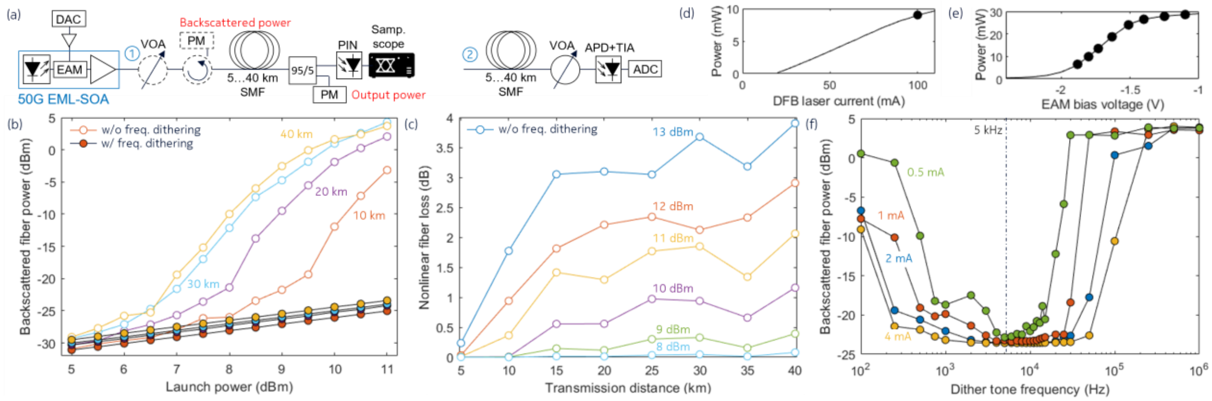

Fig. 1. (a) Setup for SBS analysis. (b) Backscattered power as a function of launch power and link length. (c) Nonlinear loss as a function of link length and launch power. (d) Laser P/I curve. (e) EAM transfer curve. (f) Optimization of dither frequency and amplitude.

3. SBS Mitigation for a Continuous-Wave Laser Operation

We first study SBS when using the EML-SOA as a continuous-wave (CW) laser. Since the SBS power threshold can be assumed to be ~3 dB higher for an OOK signal as compared to a CW tone [2], the results allow estimating SBS impairments for 50G data transmission, but with the benefit that the optical transmit power is not reduced by the modulation loss. In Fig. 1(b), we plot the backscattered power as a function of the launch power and fiber length. We observe a strong increase of backscattering for launch powers ≥ 9 dBm for 10-km links and ≥ 7 dBm for 30 km, see non-filled markers. The associated nonlinear loss, see Fig. 1(c), causes notable power depletion at the fiber output from launch powers of 11 dBm (10 km) and 9 dBm (30 km) on. For 50G OOK, we can hence expect considerable nonlinear loss for power levels of 14 dBm and 12 dBm, respectively (not displayed). Our experiments reveal that a major part of the nonlinear loss occurs over an effective length [2] of 15 km. Frequency dithering is an SBS-mitigation technique that exploits the linewidth dependency of SBS [4-5]. It can be achieved by a sine-wave modulation of the DFB laser current that is translated into a frequency modulation (FM) of the optical carrier by the laser's inherent amplitude-phase coupling, thereby effectively broadening the laser linewidth. Note that amplitude-phase coupling also exists in the EAM and SOA sections of the EML-SOA and those could as well be used for dithering. In our experiment, we apply a 5-kHz dither tone with an amplitude of 2 mApp to the laser biased at 100 mA, see Fig. 1(d), which does not lead to considerable IM at the laser output. Dithering reduces the backreflected power to a level below -25 dBm so that the fiber output power grows linearly (in dB) with launch power, see markers with colored filling in Fig. 1(b). In general, dithering needs to be fast enough to enhance the linewidth of the optical carrier beyond the SBS gain bandwidth of typically 20 to 100 MHz [4-5]. The suitable frequency range is further dictated by the specific laser design as dithering requires efficient IM-to-FM conversion. We analyze the specific requirements by measuring the backscattered power for various dither tone frequencies and amplitudes, see Fig. 1(f). We identify the low kHz range as most suitable for SBS mitigation, with an optimum at 5 kHz in good agreement with [2]. As seen, small dither tone amplitudes (e.g., 1 mA) lead to good SBS suppression. For the used laser bias of 100 mA the current in mA is half the modulation index in %. The SBS mitigation improves with stronger dither tones as stronger FM results for a given IM-to-FM conversion efficiency.

4. SBS Mitigation in a 50G TDM-PON

To maximize performance and optical power budget for 50G data transmission, the operation point of the EML-SOA needs to be optimized with respect to launch power, ER, and OMA, see Fig. 2(a), as well as the TDEC for a worst-case dispersion of 77.1 ps/nm. Each parameter needs to satisfy the ITU standard [1]. For optical launch power levels reaching/exceeding 10 dBm, SBS is an additional effect to be considered in this optimization because of the eye closure and power depletion that may result. For this reason, we measure the nonlinear loss for different EAM bias points marked in the EAM transfer curve in Fig. 1(e) after 20 and 30 km of SMF, respectively, see Fig. 2(b). For 30 km, the accumulated dispersion of 70 ps/nm is close to the defined worst case. We further vary the drive voltage amplitude to the EAM from 1.2 to 2.1 Vpp. We find that SBS can induce nonlinear losses up to 0.8 dB dependent on the EML-SOA operation point. High reverse bias voltages are associated with launch powers below 11 dBm and therefore SBS is negligible as expected from our CW analysis. With decreasing reverse bias, the effect of SBS gets more pronounced until it reaches a peak between -1.5 and -1.3 V and drops again. The cause of this drop is a matter of ongoing research. Since lower drive voltages lead to less power transfer to the spectral

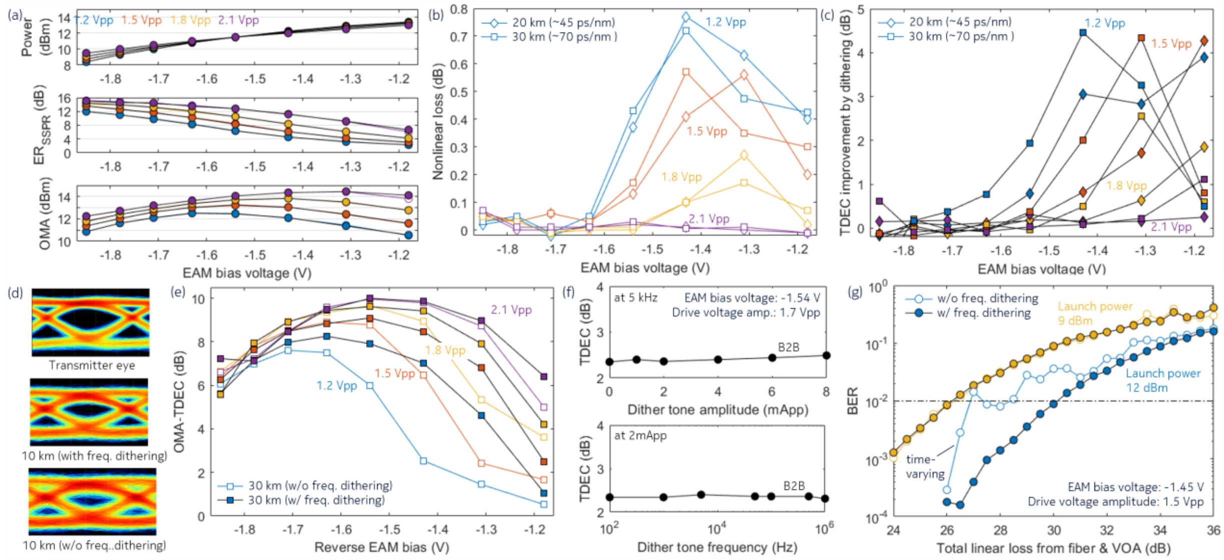

Fig. 2. SBS impact on 50G PON for various EAM bias points and drive voltage amplitudes. (a) Transmit parameters. (b) Nonlinear loss. (c) TDEC improvement by dithering. (d) Eye diagrams illustrating SBS-induced distortions. (e) OMA-TDEC optimization. (f) TDEC as a function of dither tone amplitude and frequency. (g) Optical loss budget for 30 km SMF with and without dithering.

sidebands, SBS becomes more prominent with decreasing drive voltage amplitude. SBS not only causes nonlinear loss but also eye closure due to noise, which reflects in an increasing TDEC. Both, nonlinear loss and TDEC degradation can be mitigated by dithering, see Fig. 2(c). Exemplary eye diagrams captured after 10 km SMF and shown in Fig. 2(d) visualize the eye closure when no dithering is applied. In Fig. 2(e), we display the OMA-TDEC measured after 30 km for different EML-SOA operating conditions and with and without dithering. To the left, the OMA-TDEC declines because of clamping, whereas the deterioration at the right-hand side is attributed to clamping and chirp. We observe that for drive voltage amplitudes of 1.2 and 1.5 Vpp the optimal operation point shifts when frequency dithering is used, along with an OMA-TDEC improvement of 0.2 dB and 0.65 dB, respectively. Next, we study TDEC changes when adjusting the dither tone amplitude or frequency in a back-to-back system and conclude that the transmitter performance is not affected by dithering, see Fig. 2(f). Finally, we confirm the effectiveness of dithering by measuring the bit-error ratio (BER) after 30 km SMF as a function of the total linear loss (fiber loss + splitter loss emulated by the VOA). Note that the budget is impaired by the limited responsivity of our APD at 1342.6 nm. For a launch power of 9 dBm, the cases with and without dithering lead to equivalent BER levels as no SBS is present. For 12 dBm, however, the BER degrades because of, first, additional nonlinear loss causing a reduced receive power and, second, SBS-induced noise leading to temporal power fluctuations and eye closure. Comparing the curves for 9 and 12 dBm reveals an improvement of the optical budget by 4 dB, where 1 dB might be attributed to self-phase modulation counteracting chromatic dispersion and chirp.

5. Discussion and Conclusion

We experimentally study the effect of SBS on 50G TDM-PON downstream using an EML-SOA-based OLT transmitter provided by a PON technology supplier. We observe that crucial SBS-induced performance penalties might occur depending on the specific EAM operation point and the drive voltage amplitude. Thus, SBS needs to be considered as an additional parameter in the optimization of the transmitter operation point. Since sophisticated characterization of individual transmitters before field deployment is costly, frequency dithering of the laser current is an attractive way to avoid SBS-induced impairments even if the transmitter is operated at an operation point optimized for the linear fiber regime or if its characteristics change due to temperature drift or aging effects.

6. References

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